Carolinas Regional Coastal Ocean Observing System (Carolinas RCOOS): a Model for Integration of Sub-Regional Observing Systems

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Abstract: **The Carolinas RCOOS is a sub-regional component of NOAA's Integrated Ocean Observing System (IOOS). It was formally established by an award from 2007 IOOS funding, which supported the integration of two existing sub-regional programs in the southeast: the University of South Carolina (USC)-based Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS) and the University of North Carolina Wilmington (UMCW)'s Coastal Ocean Research and Monitoring Program (CORMP). These programs had been successful in developing elements of end-to-end systems, including deployment and maintenance of observing systems, data management/analyses, model development, and outreach and partnership activities. Real time data on ocean and atmospheric conditions are transmitted from offshore buoys and pier-mounted stations, and additional non-real time data, periodic water quality data, and AUV data are also incorporated in the data management system. The transition to the Carolinas RCOOS involved elimination of some observing sites; significant increases in other observing capabilities; identification of new user applications for development; and incorporation of new partners. This successful integration of sub-regional programs has illustrated how close partnering and sharing of resources and capabilities can not only enable broader regional coverage, but can also achieve valuable operational efficiencies and enhanced potential for application development.**

I. INTRODUCTION

The Carolinas Regional Coastal Ocean Observing System (Carolinas RCOOS) was formed through the integration of two major coastal ocean observing programs in the South Atlantic Bight: the Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS) and the Coastal Ocean Research and Monitoring Program (CORMP). CORMP and Caro-COOPS were established in 2000 and 2001, respectively, as distinct subregional programs. Their adjacent geographic locations, common objectives, and complementary strengths, created an opportunity to consolidate the programs and create a more

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comprehensive and resourceful ocean observing system. The program leaders deliberately sought ways in which the activities could be integrated to achieve efficiencies and enhanced capabilities, so that by 2007 full integration was achieved and formalized through a grant from IOOS to UNCW. Furthermore, not only were existing capabilities merged, but additional capabilities and partnerships were accommodated within the broader framework.

The intentional merging of Caro-COOPS and CORMP can serve as a model for integration of subregional systems within the context of an IOOS populated by RAs. For Caro-COOPS and CORMP, the initial collaborative focus was data management. Then as CORMP assumed a greater portion of the real-time coastal monitoring activities, the two programs synchronized deployments and maintenance schedules for real-time oceanographic moorings to increase efficiencies and obtain greater economies of scale. There was also common ground relating to the application of observing data. Both programs featured predictive models developed at North Carolina State University, with the common goal of increasing the domains for storm surge predictive models to include the most vulnerable areas of the SC/NC coasts. Both programs also developed approaches and mechanisms for reaching out to the user communities. Caro-COOPS benefited from CORMP's more extensive experience in this area, but the two programs targeted different user communities and thus collectively had a broader potential for stakeholder involvement. For example, Caro-COOPS developed a strong relationship with the emergency management community, while CORMP did the same with the US Army Corps of Engineers and the fisheries and recreation communities. Both programs had established relationships with the National Weather Service (NWS) Weather Forecast Offices (WFOs).

Carolinas RCOOS has now come to represent a considerable partnering effort. It incorporates a range of observational data collected by Southeast Coastal Ocean Observing Regional Association (SECOORA) members, as well as a range of state and federal agencies and private partners. These include Caro-COOPS, CORMP, US Army Corps of Engineers (USACE) Wilmington Office and the Field Research Facility in Duck, NC (USACE FRF), the University of South Carolina Coastal Processes and Sediment Dynamics Laboratory (SCNMS), NOAA's National Weather Service, National Data Buoy Center (NDBC), and National Estuarine Research Reserve System (NERRS), the Lower Cape Fear River Program, state agencies (e.g. SC Department of Natural Resources and SC Department of Health & Environmental Control) and Down-East Instrumentation LLC. These partners share and support a common set of objectives. They each represent an array of complementary and shared expertise, and have incorporated their respective practices and techniques to achieve a high level of coordination.

The specific goals for Carolinas RCOOS are to:

- Maintain a series of inner-shelf and near shore stations that provide real time data on ocean and atmospheric conditions;
- Implement operational data streams for NDBC, USACE, NERRS, and others;
- Optimize and ensure user access to near-real-time, delayed mode, and model output data via web browser; and,
- Develop a prototype interface with the USACE Automated Model Evaluation and Diagnostics System (AutoMEDS).
- Continue to develop processes, tools, and applications that serve the broader SECOORA region and IOOS community.

II. OBSERVATIONS – OPTIMIZING PARTNERSHIPS AND OPPORTUNITIES FOR EXPANSION

The Carolinas RCOOS comprises eight offshore buoys and three pier stations (Fig. 1). Five offshore buoys and one pier station are part of the UNCW/CORMP array and three buoys and two pier stations are part of the USC/Caro-COOPS array. An additional wave buoy, part of the UNCW/CORMP array, was deployed (Fig. 2) in partnership with UC San Diego's Coastal Data Information Program (CDIP; http://cdip.ucsd.edu), which provides automated QA/AC and telemetry for the platform. All of the stations provide real-time meteorological data, water temperature, and water salinity. Six of the stations also provide hourly wave data and five of the stations provide hourly current data. The Carolinas RCOOS has worked closely with NERRs and has provided telemetry upgrades to three NERR stations within NC and SC, thereby expanding the number of real-time coastal water quality observing stations reporting within the region. All of the mooring data are fed to NOAA's NDBC, displayed on the web, and released through the NWS Telecommunications Gateway in coded messages for use by local NWS Weather Forecast Offices in Wilmington, NC and Charleston, SC. Carolinas RCOOS data, as well as partner data, are aggregated and

displayed on the program website: http://carolinasrcoos.org. The real-time data are also pushed to numerous fishing websites within the region, accessible via the NWS Marine Weather Portal, and provided to the community via local news broadcasts.

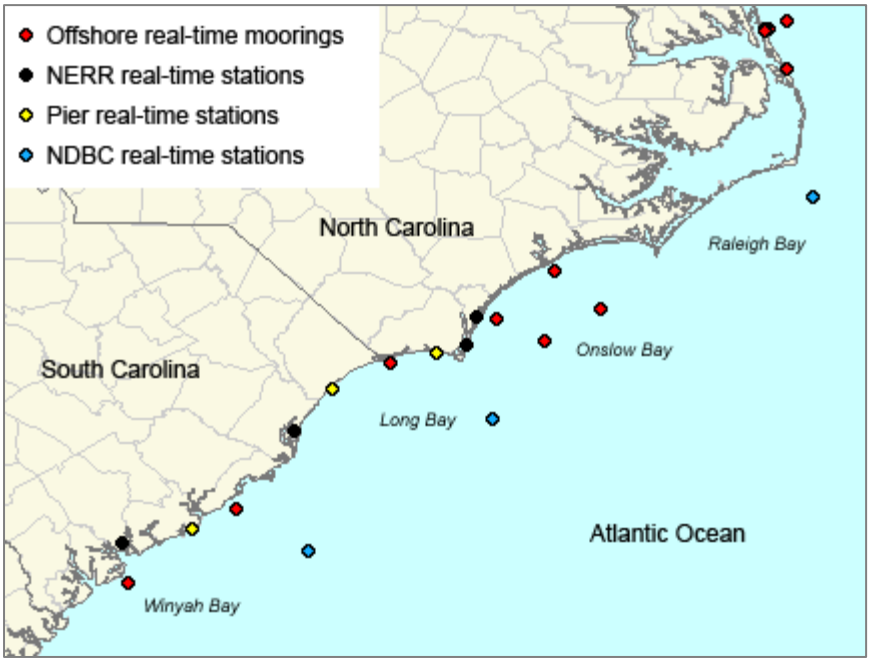

Fig. 1. The Carolinas RCOOS array.

Operations personnel at UNCW maintain the observing array and work closely with project partners to provide them with mooring updates related to the operational status of each platform. The operations personnel continually strive to identify opportunities for improvement in mooring design and performance, particularly efforts that reduce maintenance needs and increase data reporting capability. Originally, design and power constraints limited data reporting to only once every two hours, and service missions were required every 6 months using large and expensive vessels. RCOOS operations staff, using the old mooring hulls, have reconfigured the mooring sensors and telemetry package, added solar panels to reduce battery load, and changed the anchor systems so that the buoys are now modular, easier to maintain, and able to report data more frequently. Because the entire mooring does not have to be completely removed from the water for most repairs, operations staff can now use a small boat to exchange malfunctioning instruments. Further, the mooring design updates allow the buoys to remain at sea longer between servicing intervals. These factors have resulted in considerable cost savings in ship-time and personnel overtime to the Carolinas RCOOS.

Fig. 2. The wave rider buoy deployed 5 miles offshore of Wrightsville Beach, NC provides spectral wave data for use by local surfers, fishermen and boaters as well as NWS meteorologists and US Army Corps of Engineers wave modelers.

The Carolinas RCOOS observing array is designed to support safe and efficient marine transportation as well as support the National Weather Service Offices within the Carolinas. The observational network directly supports the NWS's mission to provide accurate and timely forecasts and issue life saving warnings which have a direct impact on the Nation's commerce, public safety, and decision support during critical maritime events. Observational data provides the basis for all forecasting and modeling, and without buoys marine weather conditions become extremely difficult to predict. Marine forecasters look for trends in buoy observations and analyze wind and wave data to determine actual conditions and gauge model initialization. From these analyses the NWS is able to predict the onset of hazardous marine conditions prompting

the issuance of Small Craft Advisories, Gale and Storm Warnings and Special Marine Warnings. For instance, during March 2007 the network of buoys off the Cape Fear coast indicated the passage of a cold front much earlier than models were predicting. As a result the NWS was able to adjust the start time for a Small Craft Advisory which gave mariners extra time to prepare for the stronger winds in the wake of the front. Wave buoys and pier stations also provide key information used by the NWS for surf zone and rip current forecasts. Spectral wave data, which relates wave energy to wave frequency or period, is used to identify changes in wave steepness that may impair safe navigation, especially near inlets or port entrances, and/or increase the likelihood of rip current formation along heavily used recreational beaches.

III. THE US ARMY CORPS OF ENGINEERS (USACE) CONNECTION

The USACE-Field Research Facility (FRF) and the University of North Carolina Coastal Studies Institute are working with Carolinas RCOOS partners to develop an operational interface between the RCOOS data archive and a robust coastal process model validation capability. The coastal observing stations operated by USACE FRF are included in the RCOOS networking, allowing us to fill serious gaps in the northern extent of the RCOOS domain including North Carolina's sounds. The spatial density and reliability of observing stations within the RCOOS domain has also allowed the region to become a unique regional test bed to develop, test, and evaluate a variety of coastal process models. The overall test bed concept is depicted in Fig. 2.

Specific tasks include (1) provision of operational data streams for existing USACE stations to the Carolinas RCOOS archive, (2) development of an automated data retrieval interface to support direct queries from the USACE Automated Model Evaluation and Diagnostics System (AutoMEDS) to the RCOOS observation archive, and (3) expansion of the Carolinas Observational network with critically needed observation stations in the Albemarle Sound and along the coastal Outer Banks. Our recent progress on these efforts is highlighted below.

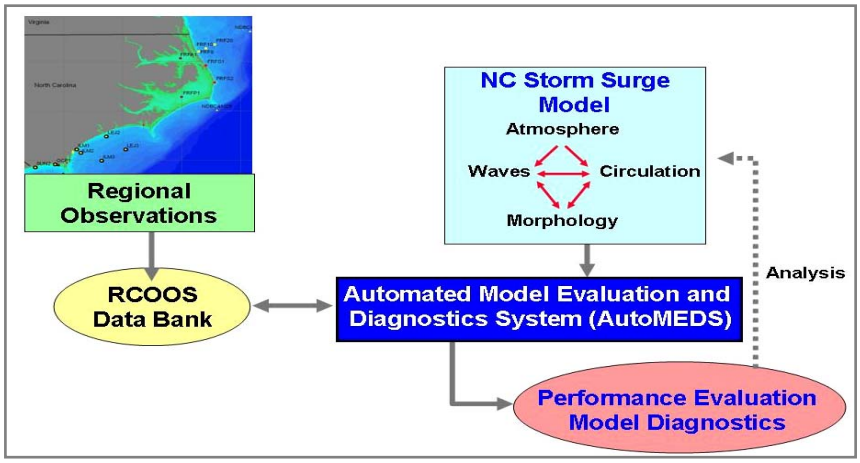

Fig. 2: Carolinas RCOOS Modeling Test Bed Concept

Throughout 2009 the USACE Automated Model Evaluation and Diagnostics System (AutoMEDS) prototype has been in continuous operation, providing daily performance updates on an operational SWAN numerical wave model application under development for the NWS. Wind and wave predications are validated at 9 coastal wave stations four times a day. AutoMEDS automatically updates model error metrics and performance scores. Presently AutoMEDS evaluates up to a month of model output at a time and carries the performance calculation through multiple months. Sample output from this application appears in Fig. 3. Individual monthly station error statistics (Fig 3a) are synthesized into overall performance scores that provide a quick-look reporting of model performance over the entire domain and for the entire observational period (Fig 3b).

The FRF team has worked with the USC and UNCW to specify the required data formats and establish a data transfer approach. The approach is modeled after the national IOOS demonstration plan that is geared towards making NDBC part of the national backbone. The data are in XML format applying the NOAA DIF schema. The data transfer is accomplished by following the Sensor Observing Service (SOS) that NDBC is using. This is performed by running a CGI script, which queries the RCOOS relational (Xenia) database to extract required observational data for model validations. Following the NDBC-IOOS guidelines facilitates an easy transition to a national archive in the event that the NDBC-IOOS

demonstration is successful. Furthermore, some specific 'data groups' (such as 2D Spectrum with Fourier Coefficient) have been created following the FRF team guidelines to ensure a straightforward way to retrieve the data while giving flexibility to the user to choose the desired wave data.

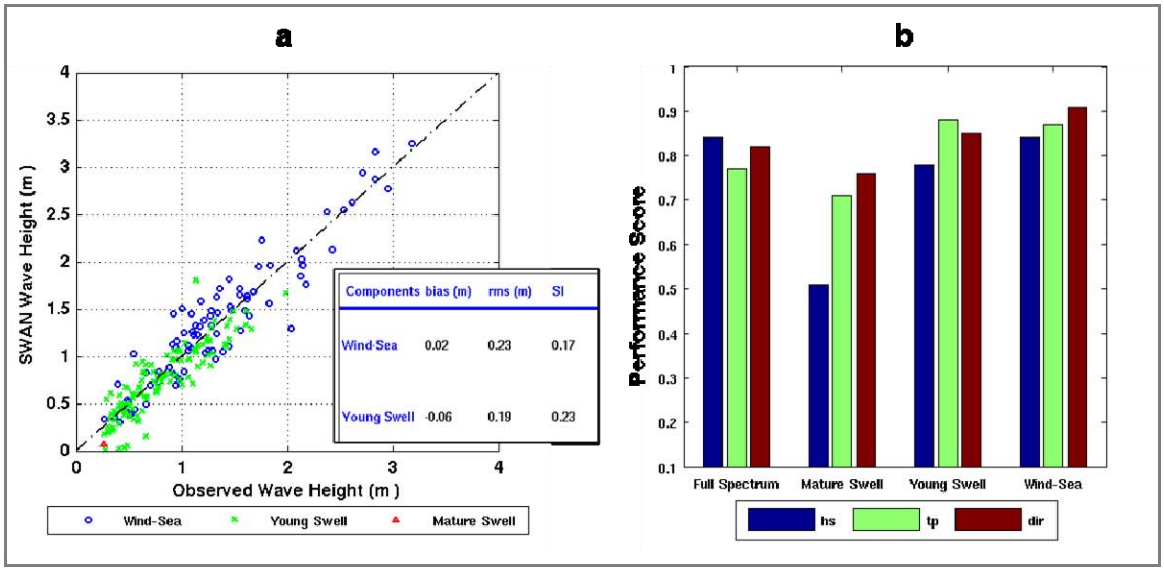

Fig 3: Sample AutoMEDS output showing regional SWAN model performance. (a) Wave height errors at station 41036 during May 2009; (b) Overall model performance scores for all stations during Jan-Aug 2009.

To fully exercise the system, RCOOS wind and wave data have been downloaded four times daily since February 2009. Water level has also been retrieved since March 2009. To ensure that the data are identical to the data downloaded through NDBC, the FRF team is conducting a thorough analysis comparing data accumulated through both sources. Fig. 4 shows a scatter plot comparing RCOOS data and NDBC data for station 41025 in April 2009. The preliminary results are very encouraging, but further examination needs to occur for some very case-specific records. Minor details such as ID conventions need to be assessed before using the RCOOS dataflow operationally in AutoMEDS.

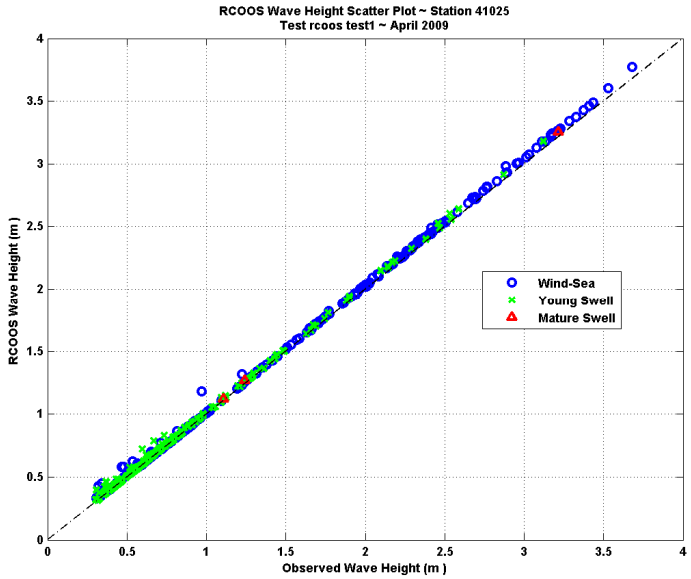

Fig. 4: RCOOS vs. NDBC (Observed) Wave Height Scatter plot for Station 41025 (LEJ2) during April 2009

IV. THE WEB PORTAL – MAXIMIZING ACCESS TO NEAR-REAL-TIME, DELAYED MODE, AND MODEL OUTPUT DATA

The Carolinas RCOOS provides access to near real-time and archived data via the RCOOS website: http://carolinasrcoos.org. The data management team continues to develop and optimize information delivery via the web browser. Particularly important are the processes and protocols for retrieving data from the various monitoring sites, aggregating those data into an appropriate database structure, and retrieving and visualizing data on a map-based platform. Data are streamed from the Carolinas sites and are retrieved from USACE, NERRS, NOAA NOS, NOAA NDBC, USGS, and NOAA NWS reporting sites. These data are transformed to obsKML, an XML format based on Google Earth KML format, which was developed in-house to support our observation-based collection, sharing, and map-based products. The obsKML files are then used to populate the Xenia observations database, a database schema that was also developed in-house for our data systems.

A critical development for Carolinas RCOOS was the browser interface, which features a highly functional map-based infrastructure for data retrieval. The open source Mapserver product was installed and configured to serve as the engine to serve the map data layers. Mapserver handles all the Web Map Service (WMS) type queries for the map and is accessible to other map developers who can potentially use WMS calls to include our data layers in their mapping applications.

The real time map incorporates data layers from various sources, including the following:

- Real Time Observation points for all platforms in the SC and NC region; both offshore and onshore platforms. Data are stored in an observation centric database at USC. The user can click on any data point to retrieve the current readings at the platform.
- Offshore Chart 11009 from NOAA used as a map overlay.
- Interpolated Sea Surface temperature data from the Ocean Circulation Group at the University of South Florida. These are merged SST data from multiple data sources, which produces a cloud free layer.
- Bathymetry layer derived from NOAA data.
- In-Situ winds that show a graphical indication of wind speed and direction. This data set is collected by USC.
- Wrecks and Obstructions layer provided by NOAA. This layer shows all the recorded wrecks off the SC and NC coasts. The user can click on the data points to retrieve the information NOAA provides about each wreck/obstruction.
- SC artificial reefs provided by the SC Department of Natural Resources and NC artificial reefs provided by the NC Department of Environment and Natural Resources which show the man made reefs off the coasts of both States. The user can click on the data point to retrieve additional structural information on the reef.

Over the past 6 months the following data layers were added:

- NC and SC Boat Ramps derived from SC Department of Natural Resources and NC Department of Environment and Natural Resources.

For certain data layers, links are provided so that the public can download them. These include:

- Real Time Data in a SQLite database file.
- SC Reefs data in a Google Earth friendly KML file (data format created in-house from the source data).
- SC Reefs data available in a GPX format, which is compatible with most GPS units. This file can be downloaded, and converted into the native GPS format using the GPS manufacturer's software.
- NC Reefs data available in a Google Earth friendly KML file (data format created in-house from the source data).
- North Carolina Reefs data available in a GPX format.
- NOAA Wrecks data available in a Google Earth friendly KML file (data format created in-house from the source data).
- NOAA Wrecks data also available in a GPX format.

Over the past 6 months, a link for data downloading was added for the following:

- SC and NC Boat Ramps dataset available in both GPX and KML formats.

To facilitate access to data and information, a number of Web Services have been developed, or are in the process of being developed. The first of these is the "alert notification." Through this service, the user can have alerts sent from one or more selected platforms when observations exceed a threshold limit provided by the user. Users can specify specific limits for a given variable, such as waves, and when measurements exceed that limit, a message is automatically sent to them. We are now working on a more complicated system that enables the user to select limits for more than one variable at a given time.

Besides interactive map based interfaces, Carolinas RCOOS also incorporates traditional CORMP data products that are highly recognized by users. These include:

- Station page which lists the station information from the last 10 reports.
- Graph and Download Page which allows people to graph and download any data collected within Carolina RCOOS region.
- Automatically generated graphics which enables the user to view the trend for each variable on every platform. These graphics are also used to monitor the data flow and the quality of the datasets.
- Station comparison page which allows people to compare multiple variables across multiple platforms.
- Implemented the CORMP QA/QC procedure on the Carolinas RCOOS datasets.
- Static map interface to present the real time data in roll over box. This is a light weight application that caters to people which want quickly scan data or have a slow machine.

Much of the effort in developing the Carolinas RCOOS website has been with a view towards transitioning the functionalities to the SECOORA web platform as soon as it is ready to accept them. There are a number of new developments implemented in Carolinas RCOOS that will add to the functionality of the SECOORA platform, which are described below.

Xenia database schema: The Xenia database schema, with its original data aggregation capability, was developed and housed at USC. This has now been implemented at UNCW, and we are now moving to transfer the data scout, which pulls the data from the observing sites to UNCW.

Pushing data to users: CORMP and Caro-COOPS data management systems depend upon users to pull data from the databases. Applications have now been developed to push data, as requested by the user. These include GeoRSS feeds for the observation sites (for users who want to subscribe to timely data updates), the e-mail alert system described above, and Twitter.

Data flow monitor: An application to continuously graph data streams for identification of data failures has been developed. The graphs are based on an aggregated count of all data values from each platform, so that plots should remain steady as long as all instruments are reporting normally. If one or more data types are not received, the fluctuation in the graph is reported automatically and the cause of data drop out can be investigated.

Email Alerts: Users can now sign up to receive an email alert whenever the winds and/or waves measurements for a user-selected platform exceed the user-defined limits.

Quality Control: A quality control system has now been implemented, which tests the following: Sensor Range, Gross Sensor Range, and Climatological Range.

Web statistics detailed tracking tool: On the server-side, scripts to better process web access logs were developed to allow better analysis of website usage statistics grouped by user and website content.

V. SUMMARY AND MOVING FORWARD

While sub-regional in scope, the Carolinas RCOOS has learned a great deal about the challenges of operating a cost-effective and user-driven ocean observing system. One of the major successes of this effort has been the merger of two smaller sub-regional efforts into a Carolinas-wide initiative at a lower cost than when each program operating independently. In addition, the program has demonstrated that two

independent programs can integrate, yet maintain their own identities and continue to serve pre-existing stakeholder issues. Significant accomplishments over the first year of the project include the following:

- Success in integrating three existing observing systems, including two with similar technologies (Caro-COOPS, CORMP) and a third (USACE Field Research Facility) with a technology that required enhancements in the data management system to enable incorporation.
- Success in integrating data management best practices, with a priority of enhancing information delivery to end-users, such as through web-based interactive maps and e-mail alerts.
- Increased frequency of data collection and dissemination to meet end user needs (e.g. upgrades to hourly reports of meteorological and oceanographic parameters for NOAA National Weather Service Forecast Offices and more frequent data updates on the web site).
- Upgrade of one North Carolina and two South Carolina NERRS meteorological and water quality stations to real time.
- Prototype Automated Model Evaluation and Diagnostics System (AutoMEDS) incorporated as a tool for evaluating and validating wave model (i.e. SWAN) performance in the Carolinas using real time observations provided by Carolinas RCOOS. This technique will be expanded to validate wind and water level predictions by the end of the project.

In summary, Carolinas RCOOS provides an excellent prototype for the development of a larger regional observing system that directly supports specific user-driven application needs. By capitalizing on existing infrastructure and by partnering with externally funded groups to develop products and applications, the Carolinas RCOOS has shown that it is possible to gradually build out an observing array into a sustained and cost-effective observing system that addresses data acquisition, management, and supports the generation of data products needed by state, federal, private and public sector users.

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